High Speed / Hypersonic Weapon Development Tool Integration

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The Integrated Hypersonic Aeromechanics Tool (IHAT) System is a tool suite for configuration optimization of high speed / hypersonic airbreathing flight vehicles. The focus of the System is on tactical weapons (Mach 4-8 regime) with relatively long range. The hypersonic flight regimes of the weapons result in unique requirements for the analysis, design, and optimization tool suite. This existing IHAT capability is being utilized and new integration enhancements are being added with other external capabilities. These new integration efforts focus on the existing IHAT System and other vehicle development tools. This paper presents a brief background on IHAT and discusses the new enhancements featured in the Virtual Missile Integration and Warfare Analysis Integration work.

The Virtual Missile Integration portion of this effort focuses on the integration of optimized weapon systems into virtual environments, such as the Integrated Battlespace Arena (IBAR). The integration of the weapon system is facilitated using a generic 6-DOF simulation. The 6-DOF is populated with aerodynamic, propulsion, and other data output from the IHAT System. The missile simulation is then interfaced to the virtual environment. The resulting virtual missile in a simulated environment facilitates CONOPS level evaluations. The optimized vehicle and the related virtual simulation are easily updated in an iterative process to allow full exploration between vehicle requirements and capabilities.

The Warfare Analysis Integration portion of this effort focuses on interfacing campaign level target set data into the IHAT System. The IHAT System calculates a Mission Effectiveness Index (MEI) for the vehicle being analyzed. The MEI value represents an overall probability of mission success related to range, time, and lethality. The IHAT System allows for optimization of the vehicle to maximize MEI. Integration of the campaign level target set allows the IHAT user to maximize campaign level performance. In addition, the resultant flyout simulation generated in the Virtual Missile Integration portion can be provided to the Warfare Analysis group for more accurate flyout performance of high-speed systems. Iteration of this process leads to a better understanding of the potential capabilities and application of the conceptual vehicle in a campaign level environment, maximizing campaign level performance.

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I. Introduction

Multiple tools exist to aid in the design and evaluation of high-speed weapons. This paper documents efforts to integrate several existing tools, including the Integrated Hypersonic Aeromechanics Tool (IHAT)[1-7]. Two major integration efforts are covered. The first is the combination of IHAT optimized vehicle output with a generic 6-degree-of-freedom (6-DOF) simulation capable of being run in a virtual environment. The second effort involves the addition of realistic campaign level target sets into the IHAT lethality module.

II. IHAT System Background

The IHAT system is a multidisciplinary analysis system for the design, analysis, and systems level optimization of high-speed air vehicles. Traditional approaches use separate efforts for each of the major design disciplines (e.g. aerodynamics, propulsion, thermal, structures). The design of high-speed or hypersonic air vehicles involves a limited design space that poses problems for designing with separated discipline teams. For hypersonic vehicles, an integrated design approach lends itself to an efficient exploration of the design space. The IHAT system was developed in an effort to integrate the preliminary design and analysis procedure. It is intended to be run by a small team of engineers, with representatives from the involved disciplines.

Figure 1 shows a graphic of the Design Structure Matrix (DSM) for the IHAT system. The system consists of a series of modules that execute in order (from upper left to lower right in Fig. 1). Each vehicle to be evaluated in IHAT requires creation of a vehicle configuration. Setup of a configuration to be run through the system consists of developing a structural model, an aerodynamic model, and a parametric geometry model to use as a baseline. In addition, further input parameters need to be defined for various analysis modules. The parametric geometry model can then be altered via chosen parameters to explore the design space around the baseline vehicle. Once the baseline vehicle configuration is in place, the modules execute in order, with each module feeding output to successive modules. In the main body of the matrix, shown in Fig. 1, the off-diagonal elements of the matrix (yellow database icons) represent data communicated from module-to-module. In this matrix block, items in the same column as a module contain data that is required to run that module, and items in the same row as a module contain data that are generated by the module. The ordering of the modules is tailored such that the number, relative impact, and ease of developing initial starting guesses for the feedback communication paths is minimized. System level optimization is accomplished by wrapping the entire module structure inside a DAKOTA optimizer loop. This allows the IHAT system to optimize a vehicle based on a given set of system level boundary conditions and target constraints. The far-left and far-right columns of the DSM show system-level inputs and outputs from the user to the system and are used to define the optimization problem. Note that the IHAT system is far too complex to display in a single figure, so Fig. 1 only shows the most significant interactions between Modules.

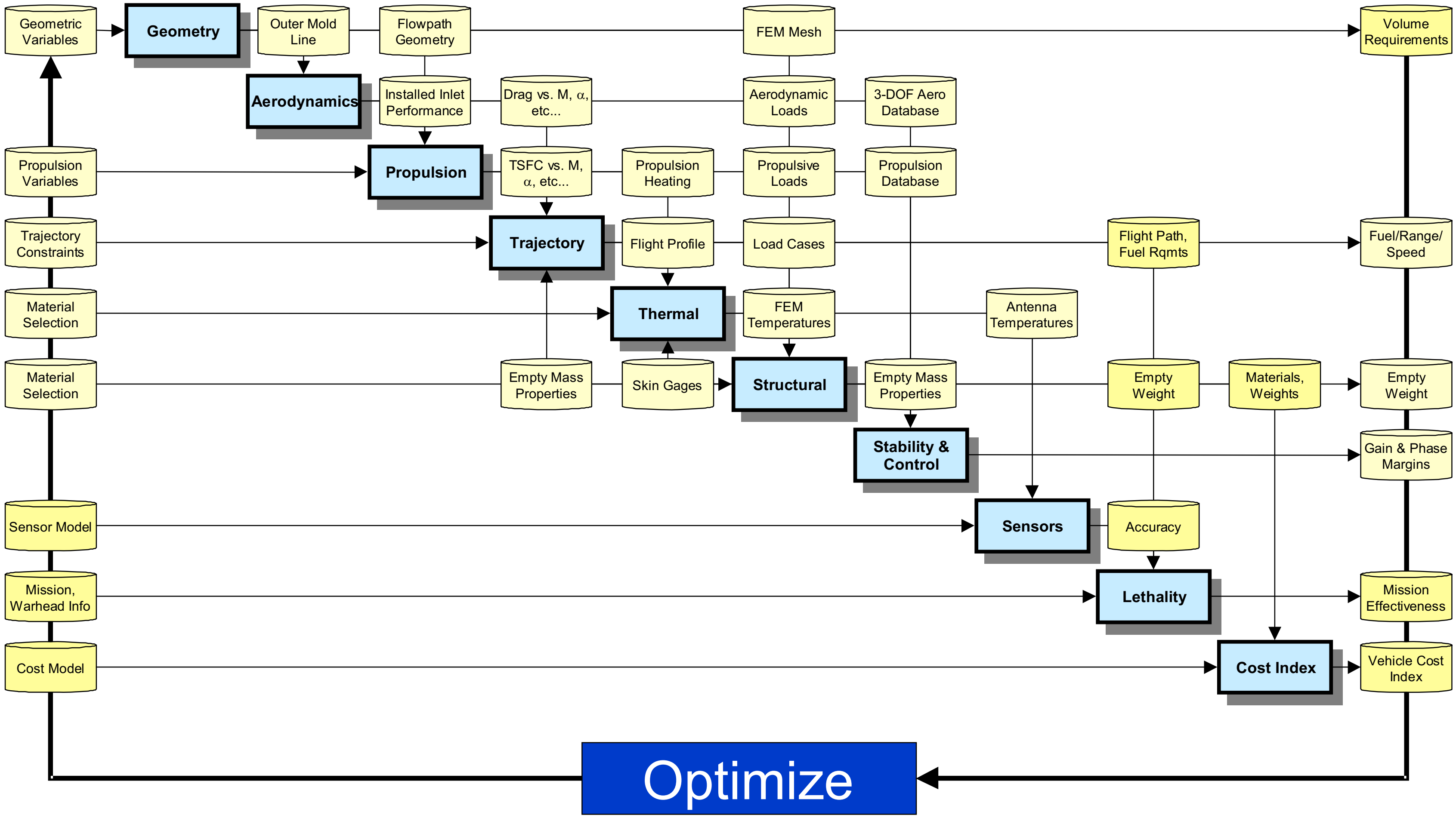

Figure 1. IHAT Design Structure Matrix

III. Virtual Missile Integration

The following section outlines the process used to integrate an IHAT optimized vehicle into a virtual missile environment.

A. Generic 6-DOF

To support insertion of an IHAT optimized vehicle into a virtual environment, a generic 6-DOF capability was developed. This 6-DOF capability was set up to utilize vehicle specific data as produced from IHAT. Data details are given in the section below. The generic 6-DOF is based on a round Earth model and is capable of utilizing linear or full aerodynamic data. Navigation is accomplished via waypoint guidance. The model supports both bank-to-turn and skid-to-turn logic and is limited to engagement of stationary targets.

B. IHAT Input

The IHAT system produces a wide array of data for each vehicle analyzed and optimized. This data is used to evaluate the vehicle and is available to support external processes. The generic 6-DOF used in this integration utilizes input from IHAT produced data in the form of vehicle mass properties, trajectory, and databases describing aerodynamic and propulsion performance. The aerodynamic database contains vehicle coefficient data as a function of altitude, mach, angle of attack, etc. The propulsion database contains engine thrust, fuel consumption rate, etc as functions of altitude, mach, and throttle (or equivalence ratio). Vehicle trajectory is captured in the form of waypoints. Waypoints are produced from a set of OTIS optimized trajectories generated from a script program external to IHAT and then provided to the 6-DOF as functions of launch altitude, launch velocity, and target range. In this case, trajectories are optimized to minimize time to target.

C. Virtual Environment

The 6-DOF, once populated with vehicle specific data from IHAT output, is capable of being inserted into a virtual environment. The simulation in the virtual environment can be used to evaluate vehicles in Concept of Operations (CONOP) scenarios. The optimized vehicle, as analyzed in IHAT, drives the simulation model flown in the virtual environment. The evaluation of the vehicle in a virtual environment allows for interaction with existing virtual assets and allows understanding and refinement of high-speed vehicle requirements. Requirements can be fed back into an IHAT optimization and the vehicle then be updated in the virtual environment in an iterative process. This process allows for more efficient evaluation of the design space while retaining a closely coupled relationship between the vehicle as evaluated at the engineering and CONOPS levels. At the writing of this paper, an IHAT driven 6-DOF has successful been integrated into the Integrated Battlespace Arena (IBAR) virtual environment located at the Naval Air Warfare Center Weapons Division.

IV. Warfare Analysis Integration

A. Target Set Input

The second part of this high-speed vehicle tool integration involves input of realistic target set data into the existing IHAT Lethality module. The IHAT system Lethality module was developed to accept user input target sets. These target sets are used to evaluate the effectiveness of the weapon being modeled. IHAT calculates a Mission Effectiveness Index (MEI) as a comparative effectiveness value for model modifications. The MEI calculation is explained in detail in the next section. To fully exercise the capability of IHAT to use MEI as a driving variable in vehicle optimization, realistic target set data was obtained from the Naval Air Warfare Center Weapons Division Warfare Analysis group. This target set was used as the target data for the Lethality module. The example target set used for this report is shown in Figure 2.

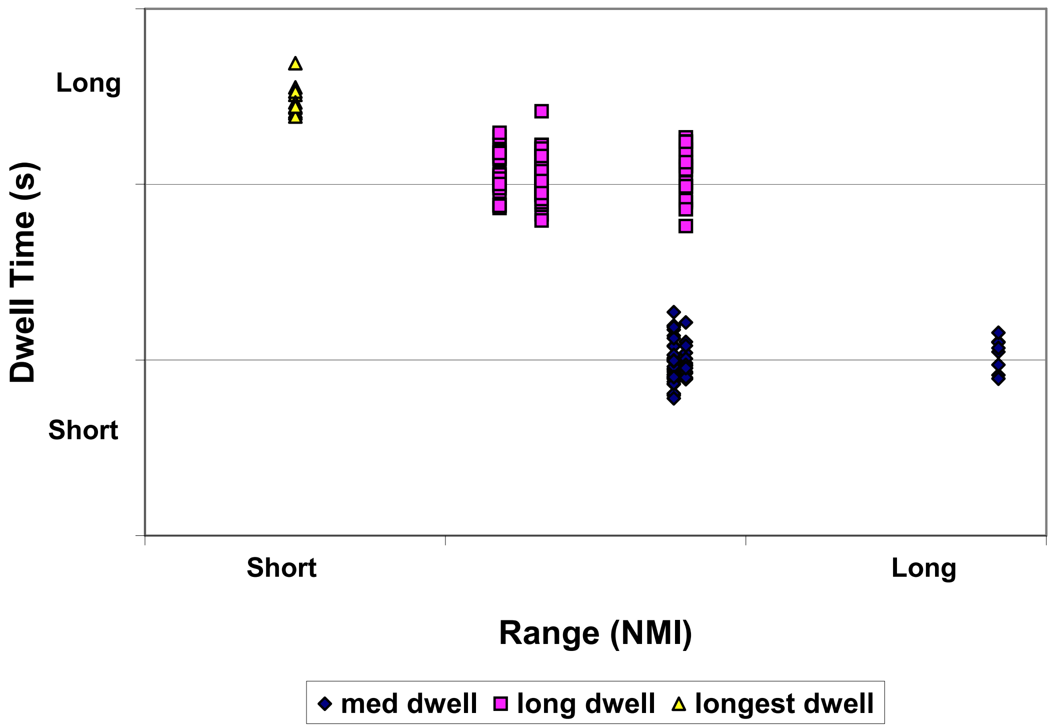

Figure 2. Example Target Set

B. Mission Effectiveness Index

The IHAT Mission Effectiveness Index (MEI) is essentially a weighted Probability of Kill (Pk) value for the entire target set. The Lethality module assesses Pk via lookup tables provided by the user. For the purpose of this exercise, generic, unclassified lookup tables were used to avoid invoking the constraints associated with classified data processing. Table 1 contains a simplified MEI example calculation. The numbers used in Table 1 are tailored to illustrate the example calculations and are not related to the target set in Fig. 2. The target set shown consists of three subsets. Each subset contains several targets. An individual Pk value is established for each target. The Pk values are then weighted by their respective percentage of the total target set. The MEI value is the sum of the individually weighted Pk values. The MEI value provides a mission level evaluation of the weapon effectiveness against the given target set.

Table 1. MEI Example Calculation

Target Group	Fraction of Total	Subgroup	Fraction of Group	Fraction of Total	PK (lookup)	PKTT	Group PKTT
SAM	0.05	SAM1	0.50	0.025	0.483	0.012	0.012
		SAM2	0.50	0.025	0.000	0.000	
TBM	0.05	TBM1	0.50	0.025	1.000	0.025	0.035
		TBM2	0.25	0.013	0.776	0.010	
		TBM3	0.25	0.013	0.000	0.000	
C&C	0.90	C&C1	0.20	0.180	0.386	0.070	0.103
		C&C2	0.20	0.180	0.187	0.034	
		C&C3	0.60	0.540	0.000	0.000	
			MEI (SUM PKTT)			**0.150**	**0.150**

C. Optimized Vehicle Example

Inside IHAT, an MEI value is calculated for each variation of the parameter vehicle. Thus, MEI can be used as the target parameter to optimize a vehicle for a given target set. The following example illustrates this process and is presented as a rudimentary example of the potential.

Given the target set contained in Fig. 2 and a baseline ramjet vehicle capable of half the range of the farthest target, the first step was to extend the range of the vehicle. Figure 3 displays a cross section of the ramjet model and defines various parametric variables built into the model. The optimizations described herein were conducted by modifying variables L1, L2, and Diameter. The ramjet was first optimized to reach a trajectory range that satisfied all the target ranges. This produced a longer and heavier vehicle to allow the addition of significant amounts of fuel.

- ***Diameter:*** Increases drag, volume, surface area; reduces stresses
- ***L1:*** Increases length and fuel tank volume
- ***L2:*** Increases length and booster/combustor size
- ***Inlet Area Ratio:*** Increases area, drag, weight, and engine performance
- ***Nozzle Area Ratio:*** Changes engine performance
- ***Fin Span:*** Increases control authority, drag, and weight

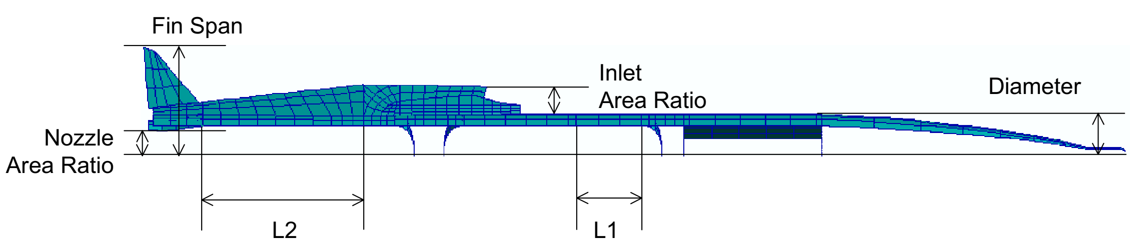

Figure 3: Ramjet Sample Problem Design Variables.

Next, the target set was included in the optimization and vehicle MEI was maximized while minimizing launch weight. Table 2 contains the results of the final optimization. Since launch weight and total length were not imposed as constraints on the vehicle, the optimizer was able to create a vehicle that attained a perfect MEI value of 1.0. Note that while vehicle diameter increased slightly, the main changes were to fuel tank length and launch weight. Warhead weight decreased significantly from the baseline vehicle. This is because the baseline warhead was notional and the target set specified did not require a large warhead. Figure 4 graphically displays the data contained in Table 2.

Table 2. MEI Optimization Results

	Baseline	Full Range	Optimized
Diameter (in)	15.0	17.6	15.9
Fuel Tank Length (in)	21.9	70.0	80.0
Combustor Length (in)	33.3	20.5	33.3
Launch Weight (lb)	1800.0	2500.0	2645.0
Range (% max target range)	50%	100%	100%
Flight Time (s)	500.0	785.4	806.5
Structural Weight (lb)	826.0	1521.4	1508.7
Booster Fuel Weight (lb)	400.0	370.4	449.4
Ramjet Fuel Weight (lb)	168.8	599.7	549.4
Warhead Weight	403.7	8.5	137.5
MEI	0.0	N/A	1.0

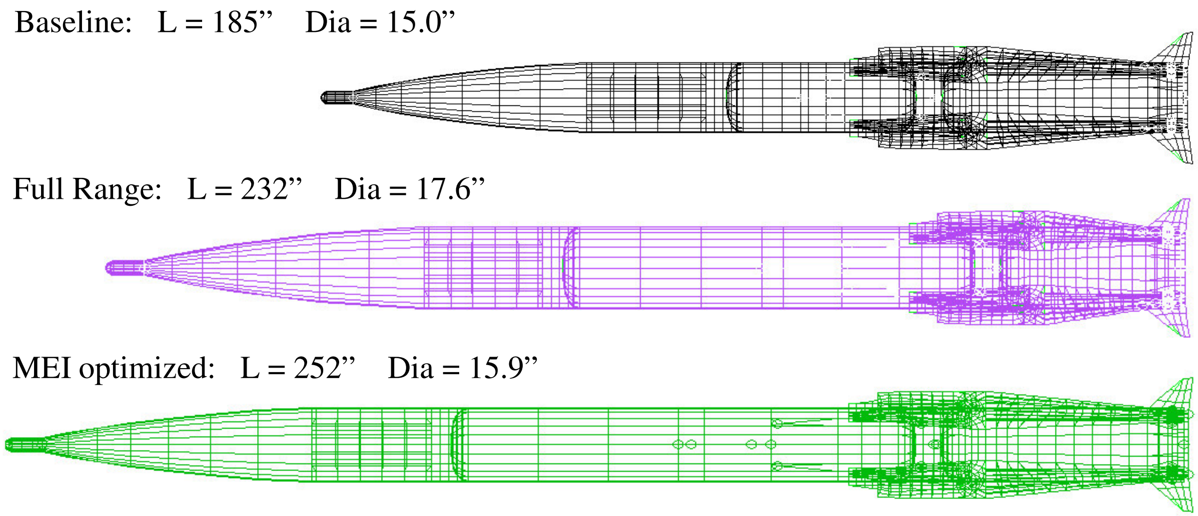

Figure 4. Optimized Vehicles

This exercise was provided as demonstration of the potential of MEI optimization. The next step in the example would be to impose hard length and launch weight constraints on the vehicle. This would reduce the optimal MEI value and would provide a more realistic vehicle.

V. Conclusion

This paper documents efforts to integrate existing high-speed weapons analysis tools. The practical combination of the IHAT system with a virtual missile environment and integration of Warfare Analysis generated target sets allows further insight and leverages each component against the whole. The integrated tools allow for better evaluation of proposed vehicle designs and more complete exploration of the solutions available.

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